Analysis of Searching Task using Chain Method in Swarm Robotics

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Abstract- Swarm robotics is an emerging field within collective mobile robotics and largely inspired by studies of insect's behavior. In defense system swarm robots are highly demanded for dangerous as well as difficult operation such as land mine detection. Land mine detection operation is similar to searching task that identifies the mines and pacifies them. From the literature survey it was found that very least of such type of problem is addressed. This project aims to search the given environment effectively, without missing out any mines; it would be better to form a chain of robots and search the area. Performance measures are affected by various factors like number of robot, area in which robots are working, presence of obstacles, etc., these factors are analyzed by Taguchi experimental design. From the analysis it was identified that speed of the chain, searching area, strategy and the interaction between searching area and strategy area were significantly affecting the performance of chain.

Keywords: Chain formation, Swarm Robotics, Strategy, Searching Area

I. INTRODUCTION

The large number of physical robots coordinates with each other to form multi robot system which is called swarm robots. “It is supposed that a desired collective behavior emerge from interactions between the robots and interactions of robots with environment. This approach emerged on the field of artificial swarm intelligence, as well as the biological studies of insects, ants and other fields in nature, where swarm behavior occurs” [1][2].

“The complex collective behavior that emerges from simple interactions among individual, and between individuals and the environment is referred to as swarm intelligence. The swarm robotics approach is characterized by the application of swarm intelligence techniques to the control of groups of robots, emphasizing principles such as decentralization, local interactions among agents, indirect communication and the use of local information” [2][3].

“In social insect colonies, even though individual members of the colony dispose of limited cognitive and acting abilities, the swarm as a whole is able to collectivelysolve complex problems such as nest building, defense, and cleaning, brood care for foraging” [4][5].

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“The research of swarm robotics is to study the design of robots, their physical body and their controlling behaviors. Relatively simple individual rules can produce a large set of complex swarm behaviors. A key component is the communication between the members of the group that build a system of constant feedback. The swarm behavior involves constant change of individual in cooperation with others, as well as the behavior of the whole group” [5].

“Most of the real time applications deal with an initial searching task. This project aims at searching the area with a chain of robots. The robot may search for a stationary prey in the given environment. While searching the predominant, the aim of robot would be to identify the prey in minimum time. Time taking is the performance measure for searching process is affected by various factors. Such as, number of robots in the chain, speed of robots in the chain, size of area and number of chains. This method is applicable for area coverage problems like cleaning a large area, land mine detection, etc” [6] [7].

II. PROBLEM DEFINITION

For analyzing the searching task using chain method, a simulated environment is considered. In this project, the robots are assumed to perform in the rectangular area. Minimum four and maximum of eight robots were used to form a chain. Each robot in the newly formed chain maintains the same distance between them to do the searching task effectively. Though the robots are not physically connected, they are virtually connected by means of sensor [8].

A. Assumptions in Simulation Process

To simulate the robots in the environment certain assumption are made, were the environment is assumed to be rectangular, robots are assumed to be autonomous and prey is assumed to be stationary.

a. Rectangular Environment

The environment of the real time problem is assumed in this study as a rectangular environment. In the rectangle, the robots have to search the prey. The prey may be placed anywhere in the rectangle. According to definition of factors affecting performance of robots the area can be varied to analysis the effect.

b. Autonomous Robots

All the robots are considered as similar robots. The robots are assumed to have the following important components [7].Microcontroller: It is heart of a robot. It controls the other main parts like motors. Two motored wheels:

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These are used to move forward and backward directions. Steering can be achieved by keeping any one wheel stationary and moving the other. Castor wheels: They prevent the robot from scraping the ground.IR (Infra-Red) module: This is used for communicating the robots among them. It is considered that the IR module has certain visible range visibility is circle in nature.

c. Prey (Stationary Object)

Prey is nothing but stationary object which weighs more than single robot and its weight is unknown to the robots. This is target object for robots. It may be placed anywhere on the environment. The location of the prey can be represented as XY coordinates.

B. Factors Considered for Analysis

Since the main objective of the project aims at analyzing the factors affecting the searching task using chain method, four major factors are identified. The factors are as follow:

S. No	Factor Description	Factor Code
1	Speed of the robot	A
2	Number of robots	B
3	Searching area	C
4	Strategy	D

Speed of robot (A) is a factor that specifies how fast the robot will be moving in the environment. Number of robots in the chain (B) is the factor that determines the number of individual units of robots required to form the chain for searching task. Searching area (C) is measured in length and breadth of the arena. Generally area is measured in meters. Strategy (D) is a factor that determines the number of chains that will be used synchronously in the simulation to search the arena. Among the four factors identified, it is important to know which factors are highly significant that mainly contributes to the increase of searching time.

III. METHODOLOGY

A. Experimental Design

Four factors were considered in the chain method: (1) Speed of robot (2) Searching Area, (3) Number of Robots in the chain and (4) Strategy. Each factor has two level and these are described in table 3.1.

S. No	Factors	Level 1	Level 2
1	Speed (A)	2m/sec	4m/sec
2	Number of Robot (B)	4	8
3	Searching Area (C)	30x40 m^2	60x30 m^2
4	Strategy (D)	Single chain	Two chain

Table 3.1 Experimental factors and individual factor levels

For the experiment the robot speed is 2m/sec in level1 and level2 speed is 4 m/sec. Four robots are used in level1 and eight robots are used in level2. The robot searching area width is 30 meter and length is 40 meter in level1. In level2 searching area width is 60 meter and length is 30 meter. Strategy is single chain in level1 and two chains in level2.

To find the significant factors in the above set of factors, it is important to conduct experiment with different levels by vary different combination of levels Player/ Stage simulation software is used.

B. Algorithm for Searching Task using Chain Method in Swarm Robots

Step 1: Start the program.

Step 2: Enabling the ports of the simulation components of robot1, robot2, robot3 and robot4 such as motor, IR module.

Step 3: Call the robots by their own address. Say r1 for robot1, r1 for robot2, r3 for robot3 and r4 for robot4.

Step 4: Initialize the variables: hcount (horizontal count) = 1, (vertical count) vcount = 1 and time = 0.

Step 5: Before moving the robots check whether any one IR module (sensor for detect the prey) of r1 or r2 or r3 or r4 detects prey, Stop the robots. Else go to step 8.

Step 6: Check that which robot detects the prey. If r1 detects the prey get the position of prey from r1. Else if r2 detects the prey get the position from r2. Else if r3 detects the prey get the position from r3. Else get position from r4.

Step 7: Print the time and position. And go to step 21.

Step 8: Move r1, r2, r3 and r4 one step forward.

Step 9: Sleep/wait 1second. Without using sleep statement the whole program will be executed within micro second. But the robot requires 1 second for moving single step. So after each and every forward movement the sleep statement should be used. Also the time variable is incremented after where ever sleep statement is executed.

Step 10: Increment horizontal count.

Step 11: Check whether horizontal movement is completed for the width of the rectangle- H. If hcount<=H go to step 4. Else go to the next step.

Step 12: Turn r1, r2, r3 and r4 90^0.

Step 13: Turning the robots also require one second. So use sleep and increment time.

Step 14: Detect for prey. If there is prey go to step. Else go to the next step.

Step 15: Move r1, r2, r3 and r4 forward. Sleep 1 sec. Increment the time. Increment the vcount.

Step 16: Check whether the robots come above the search completed area – V steps. If vcount<=V go to step 11. Else go to the next step.

Step 17: Turn r1, r2, r3 and r4 90^0. Sleep 1sec. increment the time.

Step 18: Change the sign of turning parameter. Because, in the first set if the robots turn at 90^0, in the next set the robots should turn -90^0.

Step 19: Increment count of the set of horizontal and vertical movement.

Step 20: If the rectangle is not completely covered by robots i.e. if count<=N, go to step 4. Else go to the next step. Note that if prey is available in the rectangle there is no possible of executing the else part of the program.

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Step 21: Stop the program.

IV. ANALYSIS AND RESULTS

By implementing Taguchi/ Orthogonal Array the data are collected for this chapter (OAs) experiments can be analyzed using response graph method and Analysis of Variance (ANOVA) [9].

A.Design of Experiment using Orthogonal Arrays

Consider an experiment with four factors (A, B, C and D) each at two levels. Also, the interaction AC, BC, BD and CD were considered. Select the particular orthogonal Array which satisfies the following conditions.

S. No	Factors	Levels	Degrees of Freedom
1	A	2	2-1=1
2	B	2	2-1=1
3	C	2	2-1=1
4	D	2	2-1=1
5	AC		(2-1)(2-1) = 1
6	BC		(2-1)(2-1) = 1
7	BD		(2-1)(2-1) = 1
8	CD		(2-1)(2-1) = 1
Total Degrees of Freedom			= 8

Table 4.1 Degrees of freedom

(a) Degrees of freedom of OA >df required for the experiment. Note that the degrees of freedom of OA = number of rows in the OA minus one.

(b) Possible number of interactions of OA > the number of interaction to be studied.

The OA which satisfies the required degrees of freedom is L_{16} OA. So, the required orthogonal array is L_{16} (2^{15}).

a. Linear Graph

Linear graphs facilitate the assignment of main factors and interaction to the different columns of an OA. From the standard linear graph, the part which is similar to the required linear graph is selected and superimposed. The assignment of factors and interactions to the column of L_{16} (2^{15}) OA is given in the table 4.2. Unassigned column marked with e are used to estimate the error [9].In the design layout, the row will indicate the number of experiment (trials) to be conducted. Number of column indicates the factor setting for each experiment as shown in Table 4.2. Sixteen different experiments are conducted at sixteen different setting and the responses (searching time for prey) are obtained.

Trial No.	C	B	BC	e	e	A	AC	D	CD	BD	e	e	e	e	e	Response (Sec)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	174
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	230
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	96
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	219
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	135
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1	63
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	286
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	265
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	255
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	64
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	164
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	56
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	154
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	54
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	206
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	57
Total																2478

Table 4.2 The Design layout

Factors	C	B	BC	A	AC	D	CD	BD
Level1	1468	1258	1190	1537	1383	1470	922	1128
Level2	1010	1220	1288	941	1095	1008	1556	1350

Table 4.3 Response total

Table 4.3 is developed by adding the response values corresponding to each level (level1 and level 2) of each factor. For example, level 1of factor C is sum of the observations from trials (runs) 1, 2 . . . 8 (table 6.3). That is

C1=174+230+96+219+135+63+286+265 = 1468

Similarly, the level 2 total of factor C is the sum of response value from trial 9 to 16. That is

C2= 255+64+164+56+154+54+206+57 = 1010

Thus there are 16 observations in each total.

The response total are converted into average response and given Table 4.4. Each total is divided by 8 to calculate average. The absolute difference in the average response of the two level of each factor is also recorded. This difference represents the effects of the factor. These differences are ranked starting with the highest difference as rank 1, the next highest difference as a rank 2 and so on.

From Table 4.4, it is observed that factor CD has the largest effect (rank1). And the grand average /overall mean,

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Table 4.4 Average response and ranking of factor effects

Factor	C	B	BC	A	AC	D	CD	BD
Level1	183.5	157.25	148.75	192.125	172.875	183.75	115.25	141
Level2	126.25	152.5	161	117.625	136.875	126	194.5	168.75
Difference	57.25	4.75	12.25	74.5	36	57.75	79.25	27.75
Rank	4	8	7	2	5	3	1	6

$\bar{Y}$ = Grand total of all observation ÷Total number of observation

$\bar{Y} = 2478 \div 16 = 154.88$

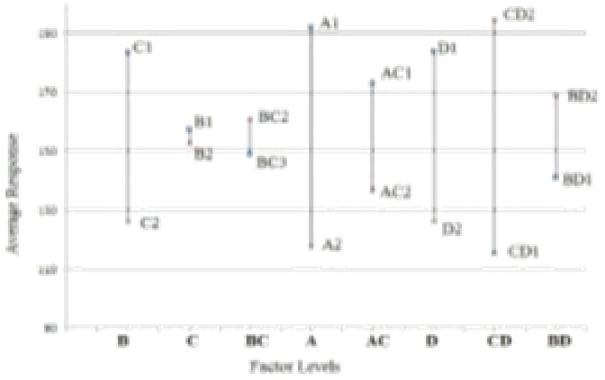

Figure 4.1 Response graph

Based on the objective of the experiment, that is whether minimization of the response or maximization, the optimum condition is selected. For minimization of response, the optimum condition is selected based on lower mean value of factor. Accordingly from response graph (Figure 4.1), select the significant effects equal to one– half of degrees of freedom of the OA used in the experiment. Considering the four factors are significant. The optimum condition is given byCD, A_2, D_2, C_2,

Since the interaction effect is significant, to find the optimum condition the interaction should be broken down into C_1D_1, C_1D_2, C_2D_1 and C_2D_2; corresponding to the pairs of combination that occurs in a two level OA; (1,1), (1,2), (2,1) and (2,2) respectively. The breakdown totals for the interaction CD is given in table 4.6. These totals are computed from the response data in L_{16}OA (Table 4.2). Note that each total is a sum of 4 observations. For minimization of response the optimum interaction component is C_2D_2.

	D1	D2
C1	691	777
C2	779	231

Table 4.5 CD Interaction breakdown response totals

Hence, for minimization, the optimum condition is C_2, A_2, C_2C_2 and D_2.

The predicted optimum response (μ_{pred}) is given by

$\mu_{pred} = \bar{Y} + (\bar{A}_2 - \bar{Y}) + (\bar{D}_2 - \bar{Y}) + (\bar{C}_2 - \bar{Y}) + [(C_2D_2 - \bar{Y}) - (\bar{C}_2 - \bar{Y}) - (\bar{D}_2 - \bar{Y})]$

μ_{pred} = 154.88+ (129-154.88) + (140-154.88) + (142.125-154.88) + [(58.25-170.63)-(129-170.63)-(142.25-170.63)]

μ_{pred} =20.5.

A. Data Analysis using Analysis of Variance (ANOVA)

The sum of squares was computed using the response total in Table 4.3

Correction Factor (CF) $= 2478^2/16 = 383780.3$

$SS_A = (1468^2 \div 8) + (1010^2 \div 8) - CF = 2220$

Similarly, the sum of squares (SS) of all main effects/factors is obtained.

SS_B=90.25, SS_C = 13110.25, SS_D = 13340.25, SS_{AC} = 5184, SS_{BC} = 600.25 SS_{BD} = 3080.25, SS_{CD} =25122.25

SS_{Total} is computed using the individual responses as usual.

Since F0.05, 1, 7

$SS_{Total} = (174^2+230^2+96^2+219^2+ \ldots + 57^2) - CF$

SS_{Total} =102257.8

Actually in all OA experiments, when determine the sum of squares of any effects, it is equivalent to the sum of squares of that column to which that effect is assigned.

The computations were summarized in Table 4.6.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F_0	C%
A	22201	1	22201	7.957653	21.71
B	90.25	1	90.25	0.032349	0.09
C	13110.25	1	13110.25	4.699195	12.82
D	13340.25	1	13340.25	4.781635	13.05
AC	5184	1	5184	1.858136	5.07
BC	600.25	1	600.25	0.215152	0.59
BD	3080.25	1	3080.25	1.104075	3.01
CD	25122.25	1	25122.25	9.004736	24.57
Error (pure)	19529.25	7	2789.893		19.09
Total	102257.8	15			100.0

$F_{0.05, 1, 7}$ =5.59 (From $F_{0.05}$ Table)

Table 4.6 ANOVA (Initial)

At 5% level of significance, factors A and CD were significant. Remaining factors were Non significant effect. The rank order based on contribution is same as that obtained earlier (response graph method). Using the pooling rule, we can pool SS_B, SS_{AC}, SS_{BC} and SS_{BD} into the error term leaving four effects in the final ANOVA (Table 4.7) equal to one - half of degrees of freedom of the experiment.

Source of Variation	SS	df	MS	F_o
A	22201	1	22201	8.57362
C	13110.3	1	13110.3	5.06294
D	13340.3	1	13340.3	5.15176
CD	25122.3	1	25122.3	9.70175
Error (Pooled)	28484	11	2589.46	
Total	102258	15		

Table 4.7 ANOVA (Final)

$F_{0.05, 1, 11}$ =4.84 (From $F_{0.05}$ Table)

At 5% level of significance, with pooled error variance, factors Speed of robot (A), Robot searching Area (C), Strategy (D) and interaction of factors C and D shows significance. This result is same as that of response graph method.

V.CONCLUSION

Swarm robots plays major role in completing task that covers the region, task that are too dangerous for humans to do, and time of completion is also important. One such task in military application is land mine detection. In this study area is assumed to be having land mine (prey) and group of robot is employed to identify it. It takes time to identify the prey if the robot moves randomly. In order to reduce the time of searching it is assumed to form a chain of robot and sweep the arena. Though chain of robots is formed, there are several factors that affect the searching time. In this study the factors are identified as speed of robot, number of robots, searching area and strategy, and simulation is carried out to find the significant factors. Taguchi's Orthogonal Arrays is used for conducting the experiments and the outcome of the analysis indicates that speed of the chain, searching area, strategy and the interaction between searching area and strategy were significantly affecting the performance of chain.

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